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GUSTAV ROBERT KIRCHHOFF.

Geheimrath Gustav Robert Kirchhoff was elected a Foreign Honorary Member of this Academy on November 9, 1870, to fill the vacancy created by the death of the eminent chemist, Thomas Graham. Kirchhoff was born in Königsberg, Prussia, on March 12, 1824. He died in Berlin on October 17, 1887, at the age of sixty-three years. After passing through the Gymnasium he continued his studies, in physics under F. E. Neumann, and in mathematics under F. J. Richelot, both eminent Professors in the University of Königsberg, taking his degree in 1847. At the age of eighteen he had selected the study of physics as his life work. As Privat-docent he started on his career of teaching and investigation, in Berlin. He was Professor Extraordinary and co-director of the Physical Institute in Breslau from 1850 to 1854. Here he formed a lifelong intimacy with the distinguished chemist, R. W. Bunsen. In 1852 Bunsen went to the University of Heidelberg as Professor of Chemistry, and Kirchhoff followed him in 1854, succeeding P. G. Jolly, who had gone to Munich, as Professor of Physics. Here he remained until 1875, when he was appointed Professor of Mathematical Physics in the University of Berlin.

This interesting description of Kirchhoff at the age of thirty, as given by Robert von Helmholtz, is quoted from the Popular Science Monthly: —

"There was, therefore, some surprise in Heidelberg when the slender, remarkably youthful, modest, even bashful North German appeared, heralded by Bunsen's warm recommendations. His refined, animated speech, his courteous and attractive demeanor, his fine sense of humor and his wit, soon won him the liking of all men with whom he came in contact. He was, therefore, a welcome participant in all the social gatherings of the circle into which he fell. His friendship with Bunsen became very close. Bunsen was thirteen years his elder, strong and broad-shouldered, with a lively, commanding temperament, making his influence felt upon every one. The two men were thus quite different in their outer aspects from one another: yet they not only pursued their great works in common, but also lived their daily social life together. They took walks in company in the environs of Heidelberg, and they travelled together during the vacations."

Before taking his degree, Kirchhoff had begun his work in original research, and published a remarkable paper on electrical conduction in a thin plate, especially a circular one. His problem was to find the current in any branch of a network of linear conductors. Starting from Ohm's familiar law, he derived two results long recognized in electrical science as Kirchhoff's laws. Between the years 1845 and 1852, thirteen other papers appeared, discussing mathematically the most difficult problems in electricity, magnetism, light, heat, sound, and elasticity in general. In 1882, when the number of his separate publications had grown to thirty-eight, Kirchhoff gathered them together, from the various periodicals in which they originally appeared, into a volume of six hundred and forty-one pages, classifying them according to subjects, and chronologically in reference to each subject. The title of this volume is *Gesammelte Abhandlungen*, Leipzig, 1882. Out of a wide range of physical problems, all of which are treated with great mathematical skill, only a few salient points can be indicated in this notice.

Ohm deduced his laws for electrical currents from assumptions which are not in agreement with those required by the facts of statical electricity. Kirchhoff proves that Ohm's laws can be derived from the electrostatic repulsion of electricity by bringing to his aid certain assumptions in reference to the question which in the electrostatic theory remain open. Neumann and Weber trusted to experiment for the value of the constant on which the intensity of induced currents depends. In 1849 Kirchhoff obtained this constant by a purely analytical treatment of the subject, and thereby made the measurements of electrical resistance absolute.

In 1877 Kirchhoff published his theory of the motion of electricity in subterrene and submarine telegraph wires. He begins with the statement that Sir William Thomson had already, in 1855, starting from the hypothesis that the influence of induction, consequent on changes in the intensity of the current, could be neglected in comparison with the influence of the changes, reached the position that the electricity in such wires was propagated according to the same laws as conducted heat. He says: "I allow myself to lay before the [Berlin] Academy a derivation of this law, which rests upon the same hypothesis, but comes out from more general principles than those given by Thomson, and to annex some formulas which, so far as I know, have not yet been published."

In 1859 Kirchhoff began his work in optics by measuring the angle between the axes of aragonite for rays corresponding to the different Frauenhofer lines. Then, with Bunsen, he studied the spectra of colored flames, and recorded the rays, present or absent. Facts then appeared, he says, which gave an unexpected solution to the origin of the Frauenhofer lines, and justified inferences as to the material quality of the atmosphere of the sun, and perhaps also of the stars. "I conclude from these observations that colored flames, showing sharp, bright lines in their spectra, so weaken rays of the same color which are sent through them that dark lines take the place of the bright ones, if a sufficiently strong light, deficient in these bright lines, is placed behind the flame. Furthermore, I conclude that the dark lines of the solar spectrum, which are not produced by the earth's atmosphere, are evoked by the presence of such substances as would in the spectrum of a flame exhibit bright lines in the same places."

Again he says: "I take this opportunity of stating a conclusion which I have reached since my earlier communication. According to the investigations of Wheatstone, Masson, Angström, and others, we know that in the spectrum of the electric spark bright lines appear, depending on the nature of the metals between which the spark occurs, and we may suppose that these lines coincide with those which would exist in the spectrum of a flame of very high temperature if we brought into it the same metal in a suitable form. I have examined the green portion of the spectrum of the electric spark between electrodes of iron, and have found in it a great number of bright lines, which seem to coincide with dark lines of the solar spectrum. In single lines the coincidence is hardly established securely, but I think that I have seen it in many groups, the brighter lines in the spark-spectrum corresponding to the darker lines in the sun's spectrum: I venture to conclude that these coincidences are not merely apparent. If the spark is taken from other metals, for example, from copper electrodes, these bright lines are wanting. I feel justified in concluding that among the ingredients of the glowing atmosphere of the sun iron is found: a conclusion which otherwise comes very close when the frequent occurrence of iron in the earth and in meteoric stones is considered."

This paper was followed, two months later, by another on the relation between the emission and absorption of light and heat. From the mechanical theory of heat Kirchhoff demonstrated mathematically the law that the proportion between the powers of emission and absorption is the same in all bodies at the same temperature, and for waves of the same length.

In 1860 Kirchhoff and Bunsen published a long paper under the title of "Chemical Analysis of Substances by Observations on their Spectra." This paper was illustrated by two plates; one representing the arrangement of the apparatus employed, and the other showing the spectra of six substances in juxtaposition with the solar spectrum. Of this work Kirchhoff writes: "From this comprehensive and prolonged investigation, the details of which I may be permitted to pass over, it comes out that the different combinations in which the metals have been tried, the variety of chemical processes in the different flames, and their vast difference of temperatures, exert no influence on the position of the lines in the spectrum of the same metal."

The last subject introduced into the *Gesammelte Abhandlungen* is the history of spectrum analysis and the analysis of the sun's atmosphere. It rarely happens to any great epoch in science that it comes wholly unheralded. Kirchhoff has candidly reviewed the various claims which have been advanced as anticipations of his discovery. Some of them were merely conjectures; others failed from too great generality and looseness of statement; the best circulated from mouth to mouth, were not published, and could not have been known to Kirchhoff previous to his own discovery; and all relied on inadequate experiments, unsupported by mathematical demonstration. Every great discovery in science, after it has been clearly proved and publicly announced, throws back a light upon its antecedents which they did not and could not originate. Spectrum analysis, with its far reaching consequences, was in the air: a few great minds felt it and predicted it; Kirchhoff demonstrated it.

In 1874, Kirchhoff published the *Vorlesungen über Mathematische Physik*, or " Lectures on Dynamics." These lectures, thirty in number, relate to the mechanics of solids and liquids, the theory of light, electricity and magnetism, and special subjects in hydro-dynamics and electro-dynamics. As Kirchhoff informs his readers in the Preface, he discusses what the phenomena are, and not their causes. Other writers are accustomed to define mechanics as the science of forces, and force as the cause which produces or strives to produce motion. Kirchhoff admits the usefulness of this definition in the development of mechanics, and to the student when it is illustrated by the experiences of ordinary life; but he thinks that there always clings to it an obscurity from which the idea of cause and resistance cannot be extricated. This obscurity manifests itself in the different views taken of the laws of inertia and the parallelogram of forces, whether they are the results of experience, axioms, or laws which can and must be known logically. Kirchhoff aimed to remove this obscurity from mechanics, even if it were only possible by a limitation of its propositions. He would describe, fully and in the simplest manner, the motions occurring in nature, ignoring their cause. Starting with the conception of space, time, and matter, he would arrive by purely mathematical paths at the general equations of mechanics. The notion of force comes in, but it is not necessary to give a complete definition of it. But the imperfection of this definition introduces no obscurity into results; for the introduction of forces in this way only serves to simplify the modes of statement, and to express briefly equations which without the help of this name would be clumsily described by words. It is sufficient for removing all obscurity, to give so wide a definition to forces that every law of mechanics in which forces are named can be expressed by equations: and this happens in a striking manner.

Of Kirchhoff and his lectures Robert von Helmholtz writes thus, as translated in the Popular Science Monthly: "His favorite work, and the one having the most enduring results, was his lectures on mathematical physics. His address was impressive by reason of the elegance and precision of his statement. Not a word was wanting, not a word was in excess; never an error, an obscurity, or an ambiguity. Remarkable also was the exactness of his calculations, — a matter of extreme difficulty to laymen. The whole material arranged itself before the eyes of the class in the form of a nicely adjusted masterwork of scientific art, so that every part exerted its full effect on the others, and to witness one of his deductions was a real æsthetic enjoyment. The complete understanding of his reasoning on these most difficult subjects implied, of course, some knowledge of the mathematical language which was his vehicle of thought; and it might happen, and did in fact sometimes happen, that a hearer could not comprehend why Kirchhoff made this particular deduction and not some other; but every one was able to follow his course of thought, consider it, and render it correctly. So that, paradoxical as it may appear, it was not impossible, without having really understood Kirchhoff, to reproduce his lectures from the notes into a respectable book. Kirchhoff was able to give his lectures uninterruptedly in Berlin for nine years. But we who heard him could remark the effort they caused him, and how he had to husband his strength. Yet he was always punctual, and the quality of his teachings was never depreciated. Finally, in 1884, the doctors forbade him to read; and although he was able to resume this his favorite occupation for a time, it was evident that his nervous system was shattered."

Kirchhoff was about fifty years old when he was called to Berlin. He had already done his greatest work on the spectrum, and published it. But his eyes had suffered from an accidental exposure to the sun, and his foot had been seriously injured in a way which impaired his general health. After 1882, the date of his *Abhandlungen*, he published a few papers.

Helmholtz, already quoted, writes: "Whether life in Berlin is favorable to scientific pursuits may well be doubted. The teacher, it is true, gains a wider, richer field of activity, but the investigator is robbed of a larger part of his time. Kirchhoff, however, was protected by his physical disability against most of the drive of the capital, and was able to labor as he had usually done."

In his power of handling physical problems, Professor Tait ranks him as the compeer of H. L. F. Helmholtz, Stokes, Sir William Thomson, and Clerk Maxwell. His discovery of spectrum analysis is an epoch-making one in science, felt equally in the humblest chemical analysis and in the remotest star and nebula.

BALFOUR STEWART.

To have achieved a permanent place in the literature of physics is no small achievement. This honor we feel that the world will accord to Professor Balfour Stewart. He was born in Edinburgh on November 1, 1828, and died on December 18, 1887. He pursued his studies at the Universities of St. Andrews and Edinburgh. Unlike most men who have devoted themselves to science, he did not linger in the shade of university walls, but began life in a mercantile office. It is said that his leaning toward physical science first strongly manifested itself on a business voyage to Australia, thus affording another instance of the effect of solation, so characteristic of sailing voyages, upon a philosophic temperament. His first scientific papers were published in the Transactions of the Physical Society of Victoria, in 1855, at the age of twenty-seven, and were entitled "On the Adaptation of the Eye to different Rays," and "On the Influence of Gravity on the Physical Condition of the Moon's Surface." It is curious to notice that these early papers were upon the subjects which were destined to engross his attention in mature life, — the subjects of light or radiant energy in general, and the effect of gravitation potential on the physical properties of matter. Shortly after his return from Australia, he abandoned business pursuits and became the assistant of Professor Forbes. In 1858 he enunciated his extension of Prévost's Law of Exchanges, and had the good fortune to express one of the great laws of nature in so simple a manner, and with such convincing proofs from his own investigations, that the future student will always connect it with the name of Balfour Stewart. Prévost had shown that a hot iron ball, for instance, surrounded by other objects, gained or lost heat in proportion to the absorbing and radiating power of the iron and the neighboring objects. Its temperature might